SUBJECT:	Fermilab Root Cause Analysis Procedure	**NUMBER:**	**1004.1002**
RESPONSIBILITY:	Quality Assurance Manager	**REVISION:**	001
APPROVED BY:	Head, Office of Quality and Best Practices	**EFFECTIVE:**	**03/31/2010**

QA

1004.1002

Fermilab
Root Cause Analysis Procedure

1.0 Purpose

The purpose of this procedure is to describe the activities required to perform root cause analysis (RCA).

2.0 Scope

This root cause analysis (RCA) procedure provides several models and methods for finding the root cause of unexpected or negative outcomes, incidents, or events that require corrective or preventive actions.

3.0 Applicability

This procedure applies to all Fermilab employees, subcontractors, and users performing root cause analysis.

4.0 Responsibilities

4.1 The Fermilab Director

- Holds management accountable for implementation of, and compliance with, this procedure

4.2 Heads of Divisions/Sections/Centers

- Ensure compliance with this procedure for their areas of responsibility including flow down of requirements and awareness
- Provide the necessary resources as appropriate to implement this procedure
- Ensure individuals within their division/section/center are trained in root cause analysis where required

4.3 The Office of Quality and Best Practices

- Manages the Fermilab Integrated Quality Assurance Program and this procedure
- Provides support to responsible management
- Determines training requirements for root cause analysis
- Maintains training materials and works with ES&H or WDRS training to provide training
- Provide QA Engineers to assist personnel in implementing root cause analysis

4.4 Employees, Subcontractors and Users

- Receive training in root cause analysis as it pertains to their work
- Notify their immediate supervisor when issues or incidents require investigation, corrective action and potential root cause analysis

4.5 Supervisors

- Notify appropriate line management when issues or incidents require investigation, corrective action and potential root cause analysis
- Determine when employees require root cause analysis training

4.6 Senior Safety Officers & Quality Assurance Representatives for Division/Section/Centers

- Assist personnel with applying root cause analysis to unexpected or negative outcomes, incidents, or events brought to their attention

5.0 Requirements

5.1 This procedure is intended to provide terminology and basic structure for problem investigations.

5.2 The output of the root cause process is an understanding of the events leading to the problem in terms of root, direct, and contributing causes along with the associated recommendations to correct the problems and to prevent recurrence.

5.3 Personnel should receive root cause analysis training where appropriate. Where required for specific positions, training is indicated on the Individual Training Needs Assessment (ITNA) and tracked in the TRAIN database. Root cause analysis training is required for Quality Assurance Engineers (QAE)s and Quality Assurance Representatives (QARs). It is recommended for Senior Safety Officers (SSOs).

5.4 Assignment of personnel to an investigation should consider training/experience with RCA as well as with the technology and processes to be investigated. Assignment of someone independent of the area being evaluated but with RCA experience may be useful in providing an objective assessment.

5.5 Containment and remedial actions to put the affected process in a safe condition and to preclude recurrence shall be taken prior to beginning a root cause investigation. These actions shall be reviewed during the conduct of the RCA to gain clarity of the problem symptoms, scope and evidence.

5.6 A graded approach should be used when determining the applicability of this procedure to problem solving at Fermilab. This requires considering frequency, cost, and impact on operations or safety issues associated with the problem being addressed. A graded approach includes determining the type of root cause method to be used – varying from an individual performing a simple, informal review of the problem to the establishment of a team and the use of formal, detailed processes to review a problem.

5.6.1 Appendices 1 through 2-6 provide information on some of the root cause methods and tools that may be used at Fermilab.

5.7 Perform the investigation

NOTE: The order in which the following steps occur may vary depending on urgency of the problem, degree of problem understanding at the beginning of the investigation, and the need to protect/preserve evidence.

5.7.1 Step 1 - Define the problem.

Define the problem by developing a clear, complete and concise statement which includes what the problem is, who was involved, where it occurred or was identified, when it occurred or was identified and the magnitude (e.g., frequency, impact). Operating conditions or precursor information which may provide additional details for consideration might also be required. This problem statement will become more refined and detailed as the analysis is conducted.

5.7.1.1 Choose the best methods and tools for performing the root cause analysis from appendices 2-1 – 2-6.

There are methods and tools in addition to those listed in the appendices. Fermilab is not limited to the methods contained in this procedure; however, the chosen method should be recorded and its process followed to provide the best opportunity for reaching a successful conclusion.

Human Performance Fundamentals provide tools for understanding human error and how to cope with it and is not part of this procedure. However it could be one of the approaches employed when investigating unexpected or negative outcomes involving human performance or "error proofing" procedures and communications in the context of tools, tasks, and operating environment. RCA and HPF may be complementary and are not mutually exclusive.

5.7.2 Step 2 - Understand the Process

Identify initial boundaries of the system to be analyzed. Gain a high-level understanding of the normal sequence of operation of the system which failed by using a Process Analysis Tool from Appendix 2-2 to create a process flowchart and timeline showing the activities involved.

5.7.3 Step 3 - Identify Possible Causes

Develop hypotheses regarding the most logical possible causes of the problem under investigation or at least which steps of the process contributed to the problem.

5.7.3.1 Identify which steps in the flowchart most likely could and could not cause the problem.

5.7.3.2 Use Cause Analysis Tools from Appendices 2-1 and 2-3 to identify failure modes, cause categories, or other groupings of causes

5.7.3.3 Identify barriers in the system which may have failed by using Cause Analysis Tools from Appendices 2-2 and 2-3. Note that such barriers could include those items intended to prevent the problem and/or intended to detect the problem

5.7.3.4 Assess whether there have been any changes made in the system prior to the time of the problem which may have led to the occurrence

5.7.3.5 Use an Idea Creation Tool from Appendix 2-3 to brainstorm a list of possible causes. The brainstorming process might be done as an open discussion, or might use structured methods such as looking at the process flowchart or using a cause & effect diagram or other causal analysis tool to assist. Anonymous brainstorming might be useful if openness of participants is a concern.

5.7.4 Step 4 - Collect Data

Using the tools described or referenced in Appendix 2-4 collect data to refute or support hypotheses developed in step 3 regarding the causes that had the greatest impact on problem initiation. In addition to conventional data collection, evidence gathering should include interviews of personnel involved with designing, operating and/or maintaining the system which failed; observation of the processes in action when possible (e.g., in real-time or video/computer recording); scientific analysis of failed system components; and reviews of relevant organizational records related to planning, carrying out and maintaining the system.

5.7.5 Step 5 - Analyze the Data

Use Analysis Tools from Appendix 2-5 to analyze data for evidence that allows determination of which of the possible causes had the greatest impact on problem initiation.

5.7.6 Refine the problem definition based on current conclusions, then repeat the system understanding, possible cause, and evidence gathering & analysis sequence until the level of cause is deemed sufficient for the significance of the problem. For low risk or impact problems finding the direct cause(s) may be sufficient, while for more significant problems the root cause(s) (also known as system causes) should also be found.

5.7.7 The Evaluation and Decision Making Tools of Appendix 2-6 may be used to determine the extent of condition (EOC)

5.8 Implement solutions

5.8.1 Identify potential solutions for each identified cause and use the Evaluation and Decision Making Tools from Appendix 2-6 to consider which to implement based on criteria such as risk associated with the problem if left uncorrected, technical feasibility, cost, timing, and potential risks for creating other problems.

5.8.2 Develop an implementation plan including actions, personnel assigned, timing/milestones, and performance metrics. Performance metrics should include both short and long-term measures along with a communications component to specify what information should be communicated, to whom, and frequency (to report progress and effect). These items should be input in to a corrective action system.

5.8.2.1 If required, revise related policies, procedures and other system management documents and provide appropriate training on the changes. Implement the changes and monitor results.

5.9 Once success has been achieved results should be communicated as appropriate within the organization to share lessons learned about both root causes for the problem as well as how to perform effective investigations

5.10 A report of the investigation should be created which includes, at a minimum, the original problem definition, actual causes found and supporting discussion/evidence, solutions selected and rationale for their selection. An addendum to the report should be created later when results of the changes can be validated. This can be part of the commitment tracking, such as found in the Fermilab Corrective and Preventative Action procedure in lieu of an addendum to the report.

6.0 Review Cycle

This procedure shall be reviewed for accuracy and relevance on at least a three year cycle

6.1 Document Owner

OQBP QA Manager

6.2 Reviewers
OQBP Head
Division/section/center QARs
OQBP Staff

6.3 Approver
OQBP

7.0 Policy and Program Documents

Directors Policy #10, Quality Assurance
1001 Fermilab Integrated Quality Assurance (IQA) Chapter 3
1004.1001 Corrective & Preventive Action Procedure
Fermilab Environment Safety & Health Manual (FESHM) Chapter 3010, Significant and Reportable Occurrences

8.0 Definitions

Contributing cause – The causes which did not initiate the problem, but had they not existed the problem could not have occurred or would have been less severe.

Direct cause –The cause which immediately resulted in the problem. This is also known as the physical or proximate cause.

Extent of condition (EOC) – Determination of the degree to which a problem or cause may exist in other portions of the system or similar systems.

Incident – An occurrence which deviates from planned requirements (activities or results), or expected outcomes which may range from a simple procedural noncompliance with minimal risk to a accident/event having substantial risk to personnel.

Root Cause – The cause which created the direct cause and, which if not corrected is likely to result in recurrence of the same or similar problems. See attachment 2 in DOE G 231.1-2 for a tree of system-level causes. Root Cause is also known as the system cause.

Root cause analysis (RCA) - A logical thinking process using deductive and inductive searches to collect evidence to support or deny actual causes of a problem.

> DOE-NE-STD-1004-92 lists several approaches to RCA, including event & causal factor analysis, change analysis, barrier analysis, management oversight and risk tree analysis (MORT), human performance fundamentals evaluation and Kepner-Tregoe problem solving and decision making. Widely known commercial approaches (and related training) to RCA include Apollo, 8-Discipline, ProAct, Six Sigma and TapRoot. Widely known more generic models are also available from organizations such as ASQ and Toyota.

9.0 References

DOE O 414.1C *Quality Assurance* – Contractor Requirements Document, Attachment 2 Section X – Corrective & Preventive Action

DOE-NE-STD-1004-92 – Root Cause Analysis Guidance Document

DOE G 231.1-2 – Occurrence Reporting Causal Analysis Guide

Appendix 1 – Root Cause Analysis Examples

Appendix 1-1 RCA for a Repetitive Problem

During an internal assessment it was found that some employees were not wearing appropriate personal protection equipment (PPE). The following audit finding was written: "three personnel were not wearing the PPE required for the areas in which they were working."

This is not a complete problem statement since it only captures symptoms of the problem and does not consider time. If the corrective action process deemed root cause analysis to be necessary the investigator(s) would need to develop a complete problem statement. They would first get specifics on the individuals, equipment, and work locations involved in the finding, then review organizational records (e.g., other assessment reports, security videos) and collect additional data through observation to see the degree of the problem over time.

The information collected is analyzed using two different graphic analysis tools: Pareto diagrams (to see what patterns exist between the various forms of the problem) and run charts (to see the degree of variation over time). See Appendix 2-1 for additional information on Run Charts and Pareto Charts.

The Pareto diagram in Figure 1 indicates that 54.5% of missing PPE is of type b, while the Pareto diagram in Figure 2 shows that work areas 2 and 3 account for 75% of missing PPE.

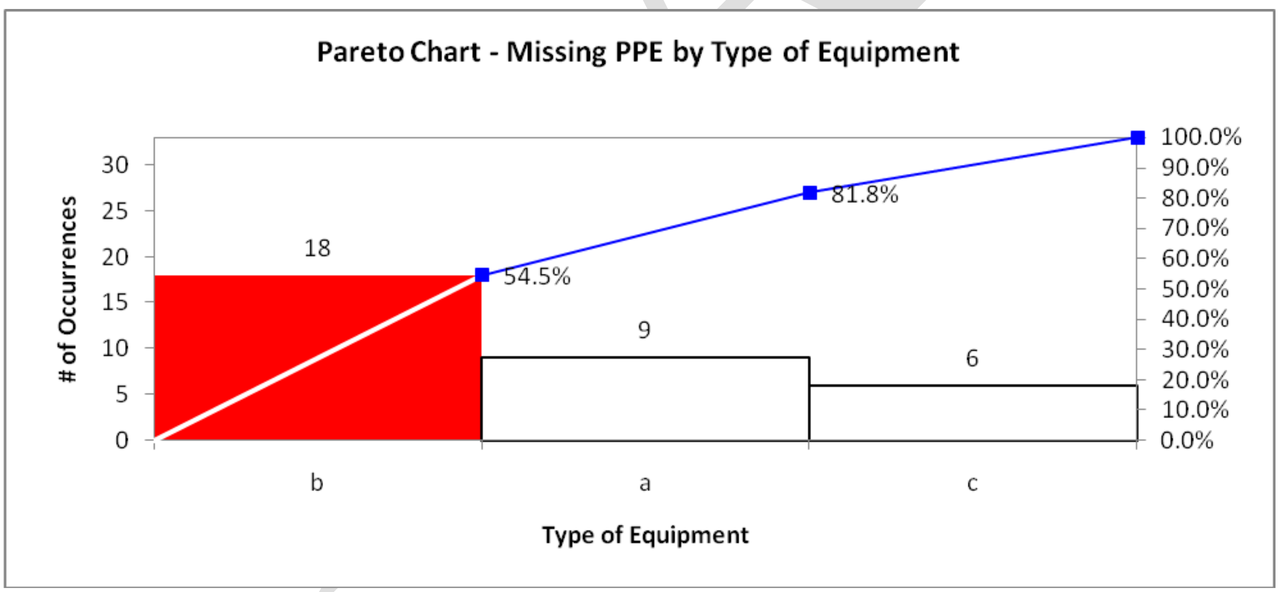


Figure 1 Missing PPE by Type of Equipment Pareto Chart

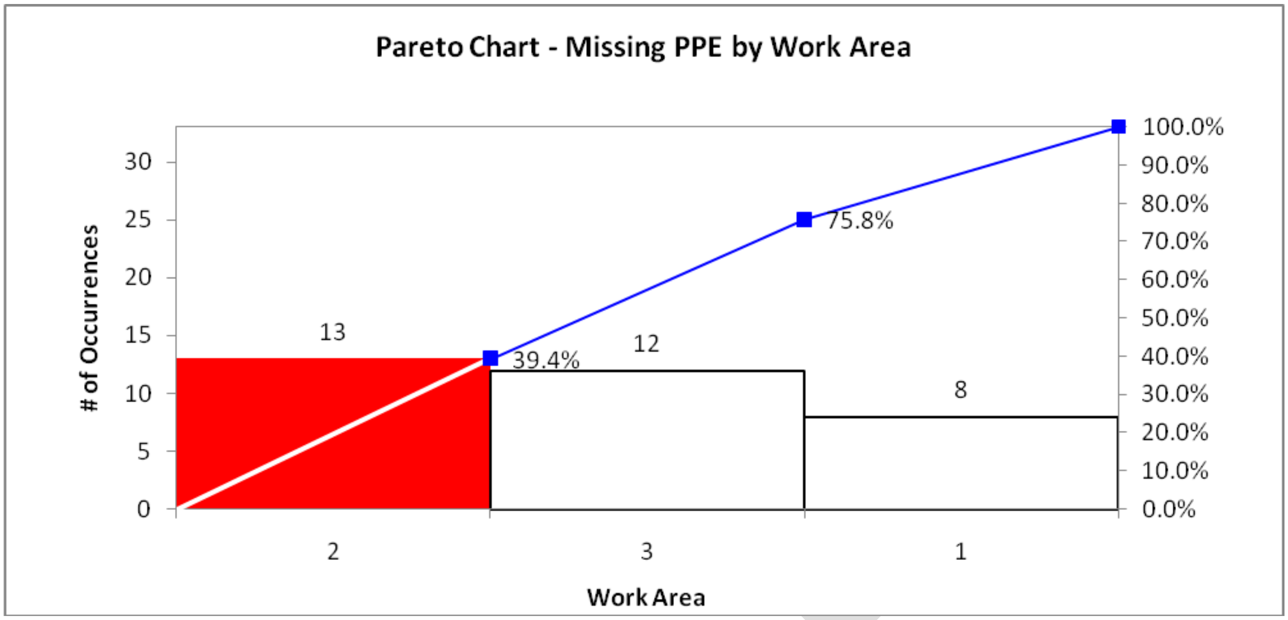


Figure 2 Missing PPE by Work Area Pareto Chart

The Pareto charts help determine whether the problem scope will include all types of equipment and all areas simultaneously, or whether to focus on the most significant issue first. After the most significant issue has been resolved, the others can be addressed. Assume that it is decided to focus on equipment type b first, since it is responsible for over 50% of total occurrences and has a higher associated risk.

The investigators then need to determine how the problem behaves over time. If possible the data would be organized into a run chart to determine whether the problem is inherent (e.g., relatively consistent over time) or suddenly began at a particular point in time.

Figure 3 shows a run chart with two different lines, each indicating one of these two situations. The red line is an example of a problem that suddenly changes at a particular point in time. The blue line is an example of an inherent problem that behaves consistently over time. The consistent, Stable # of Occurrences line will be used for the remainder of this example.

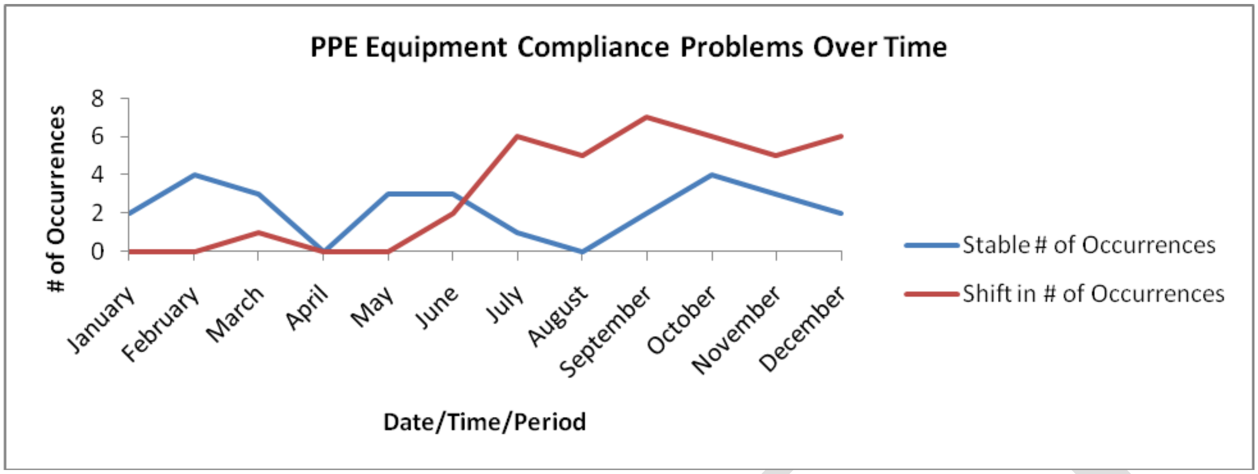


Figure 3 Run Chart of PPE Compliance over time

The investigators need to understand the system for PPE management. The process flowchart is documented below in figure 4. For additional information on flow charts, see Appendix 2-2.

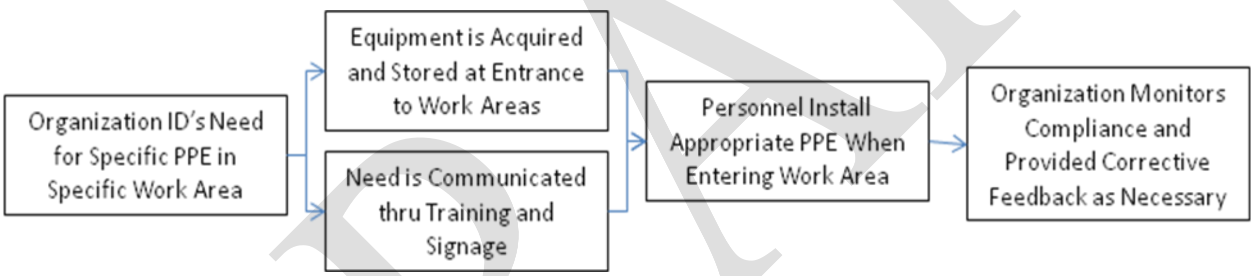


Figure 4 - PPE management flow chart

The next step is to identify possible causes for personnel not wearing PPE. Reviewing the process flowchart yields the following conclusions:

- The first step could not cause the problem, since if the requirement didn't exist, compliance would not need to exist.
- Acquisition and storage could cause the problem, since if it were not available, personnel could not wear it. However this would be a contributing cause, since if the equipment was not available, personnel should not enter the area without it.
- Lack of effective communication of the need could certainly cause the problem, as could people simply not putting the PPE on even though they know it is required.
- Although lack of monitoring and feedback might not actually cause the problem, it might contribute to the problem by allowing the culture of the organization to be one where lack of compliance was acceptable, which means people might ignore the requirement.

Another way to identify possible causes is the use of the 5-whys. Often a logic tree is used to document the output from the 5 whys. See Appendix 2-3 for additional information on the 5-whys and Logic Trees. A partial example of a logic tree for this problem can be found below in figure 5:

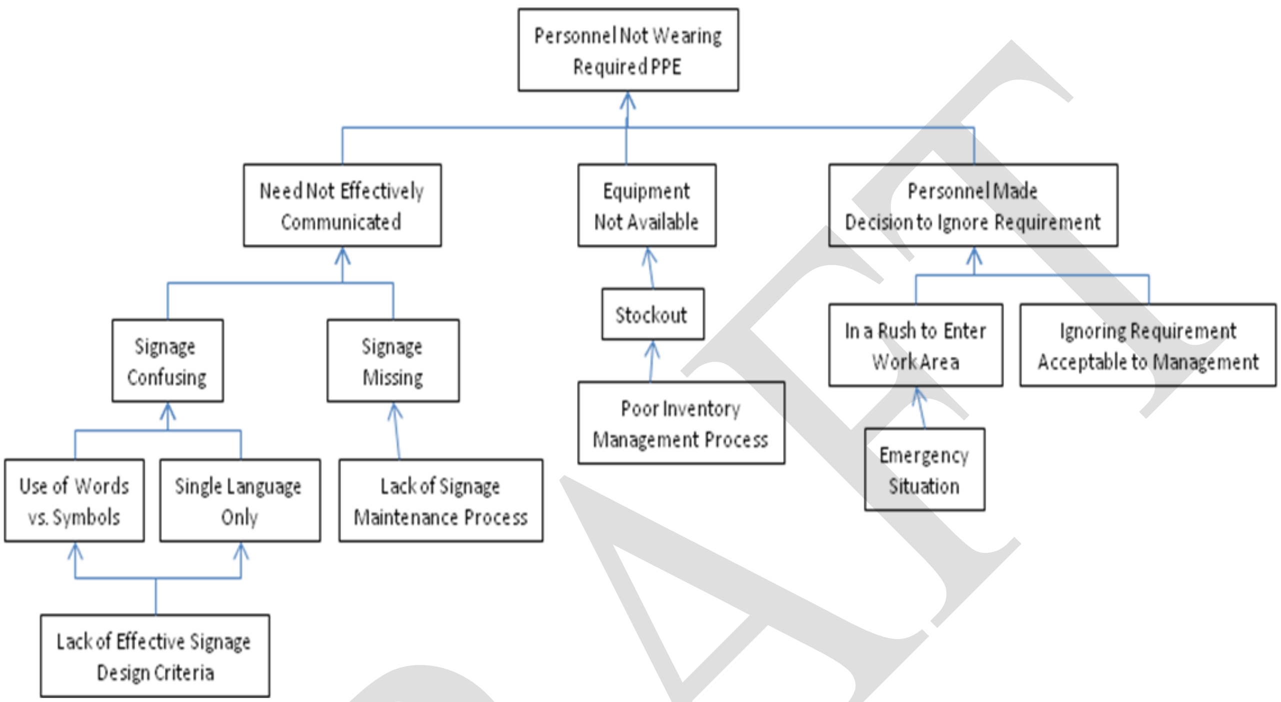


Figure 5 - Logic Tree representing the application of the 5-whys tool for the PPE Problem

Another way to identify causes is through barrier analysis. Barrier analysis focuses on what controls are in place to either prevent or detect occurrences where people fail to use required PPE. See Appendix 2-3 for additional information on Barrier Analysis.

For example, when looking through the process flowchart one finds that both communicating the requirement for PPE (e.g., through training & signage) and monitoring of PPE compliance are barriers, that is, steps in the process intended to prevent and detect (respectively) the problem. If either of these steps fails it is likely that the problem will exist and perhaps also not be detected.

Change analysis is likely to only be useful in those instances where a significant shift in performance has been detected. If the level of PPE noncompliance is relatively steady then there are unlikely to have been any organization, process, or procedural changes which caused the problem. On the other hand if there is a significant increase in noncompliance then it is quite possible that some change has occurred which led to the problem. An example might be a sudden influx of untrained contract personnel, introduction of a new type of PPE which causes great discomfort for personnel, or a shortage of PPE.

Another method of determining possible causes is brainstorming. it is often helpful to use a cause and effect diagram to categorize the output using the 7 M's (manpower, methods, materials, machinery, measurement, mother nature, and management) or the 4 P's (policies, procedures, plant, and people) See

Appendix 2-3 for additional information on the use of brainstorming and Cause and Effect Diagrams. Figure 6 below is a partial example of a cause & effect diagram created from a brainstorming session on the PPE problem

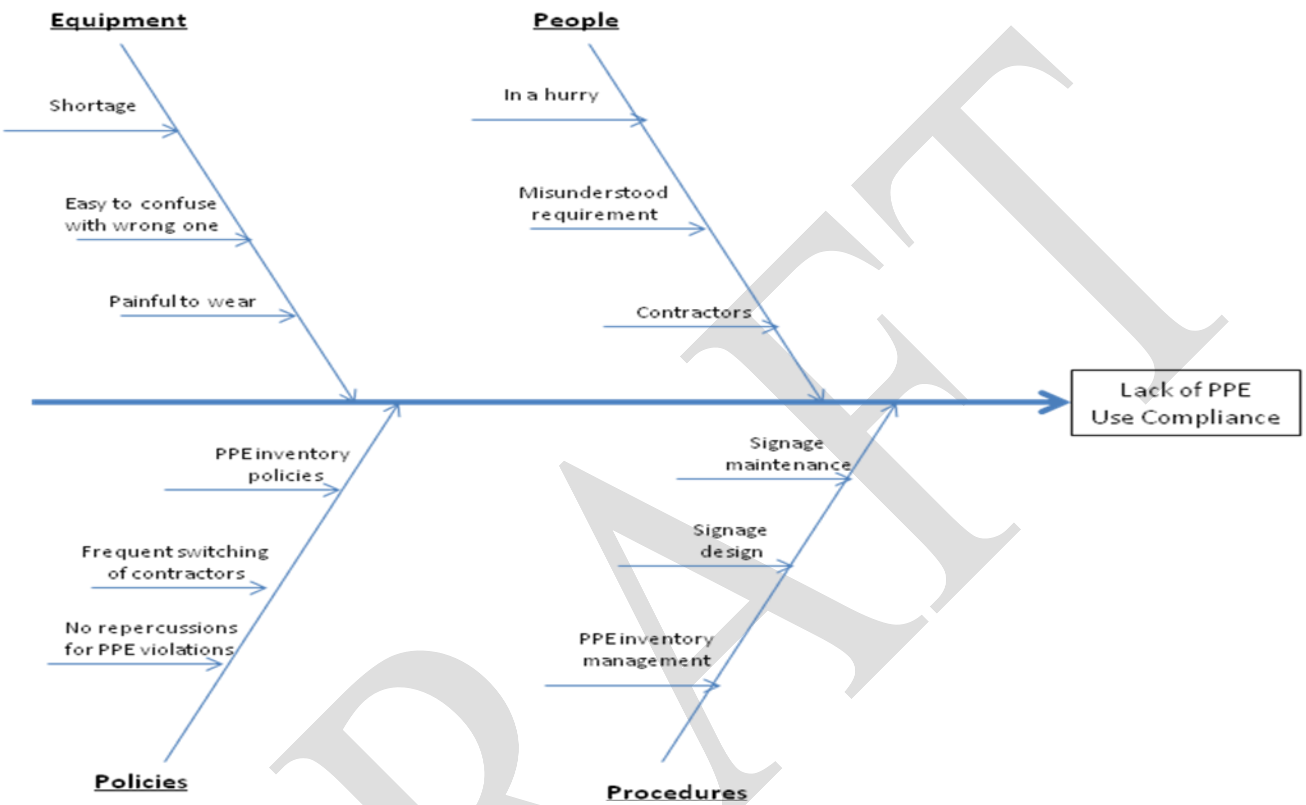


Figure 6 – Cause and Effect Diagram for the PPE problem

Regardless of the method used to identify possible causes, it is likely that several will be identified. There is therefore a need for a method to reduce the list to the most likely causes. Some of these evaluation and decision making methods are:

- Ask whether it is logically possible – In the PPE problem discussed above, elimination of the first box in the flowchart as a possible cause used this method. If a requirement has not been defined there is nothing to write a nonconformity against. That is, there is no requirement to be violated.
- Determine what data can confirm or deny the cause. In some cases investigators can quickly analyze existing data that will indicate whether a specific cause, (or group of causes in the case of the PPE flowchart and logic tree), is contributing to the problem.
    - Group Discussion -When logic can't rule causes out and data collection is too time consuming to cover a large number of causes, investigators can combine information from

several knowledgeable sources to estimate which causes are most likely. It is important that individual estimates, ranks or votes be established independently, before being communicated to the group.

- Probability – Each individual predicts the absolute probability (e.g., on a scale of 1 to 10) of each cause, or splits 100 points among all the causes in a manner indicating relative probability. The probabilities of all individuals are then summed for each cause, and the higher ones are investigated first.
- Nominal Group Technique (NGT) – With NGT each person ranks the causes from 1 to n in order of priority. Total points for each cause are then calculated and those with the lowest total score (highest priority) are the focus See Appendix 2-6 for additional information on Nominal Group Technique. Multi-voting – During multi-voting each member of the group votes for which causes should receive highest priority. Each person has x votes, where x = n/2+1, and n = the number of causes. Each person can allocate their votes as they deem appropriate. The total number of votes for each cause is then calculated, and those which received a low number are dropped. The voting process is repeated until the number of causes has been reduced to what is deemed acceptable for more in-depth investigation. See Appendix 2-6 for additional information on Multi-Voting.

For the repetitive PPE problem investigators first look at the patterns of failure. Since it is an ongoing problem with a relatively high degree of occurrence one could eliminate “emergencies” as being the logical cause unless the work areas consistently encounter such situations. Availability of the required equipment is easily checked through a review of the equipment storage locations and interviews of personnel who did not wear the equipment. Testing of signage effectiveness is done by asking those same personnel whether or not the work area required PPE, and if so, how they know. Existence of signage in the proper place is also reviewed, as is whether personnel properly interpret the signs. If none of the above is the cause, the only possible cause left (from the logic tree) is that people believe it is ok to not wear the PPE.

This indicates that people believe management does not take the PPE policy seriously. Investigators would look for what actions had been taken when previous PPE problems were found. If the answer is “nothing,” then evidence indicates that management tolerates this behavior. This is the root or system cause. Personnel making the decision to not wear PPE are the physical causes.

Before moving to solutions the investigators determine the degree to which the findings are consistent or different for different PPE devices. If the same causes are found, findings of the investigation would be reported to management. Finally, the investigators would determine and implement solutions, and follow up to determine their effectiveness.

Appendix 1-2 RCA for an Incident

A large electronic instrument was transported from room X to room Y in Building A on a cart. It fell off the cart onto the concrete floor. Damage was extensive and a root cause investigation was initiated.

The investigators ensured that the device had been secured and determined whether there were any injuries to personnel which needed to be attended to. They then interviewed personnel involved in moving the device as well as others who were in the areas where the device was loaded, transported, and where the incident occurred. They also walked the areas to look for anything out of the ordinary. Some of their questions included:

- Why was it moved?
- At what time was it loaded and by whom?
- What did the work order indicate was required for transport?
- Was there adequate space and equipment to allow loading the device properly?
- How was it secured for transport?
- When was it moved and by whom?
- Where did it fall off the cart and how far was this from the loading location?
- What occurred just prior to or at the same time device fell?
- When it fell, what part hit the ground first, and what happened next?
- What did the transport personnel do as it was falling and after it fell?
- What indications of damage are there on the device?

They then created the following timeline:

Time	Action	Comments/Questions
Day before	Received request from Engineering to deliver device to Room Y next morning	
9:15-9.20	Cart acquired and moved to room X by Tech 1	Size of cart appropriate?
9:30-10:00	Device lifted onto cart with winch 265 by Tech 1 and Tech 3	Due to short transport distance did not strap device to cart
10:15	Opened door and pushed cart w/ device into hallway	Techs 1 & 3
	Pushed down hallway to door of room Y by techs	Speed did not appear to be a factor
	Door to room Y opened by Supervisor	Door opened suddenly and hit corner of device; door opens outward and has no window
	Device fell to floor	Hit first on top, right-front corner, then flat on top
10:20	Reported incident to Engineering	

The information is organized into a process flowchart demonstrating the actions leading up to the event. For each step, possible causes for the incident are identified in the ovals.

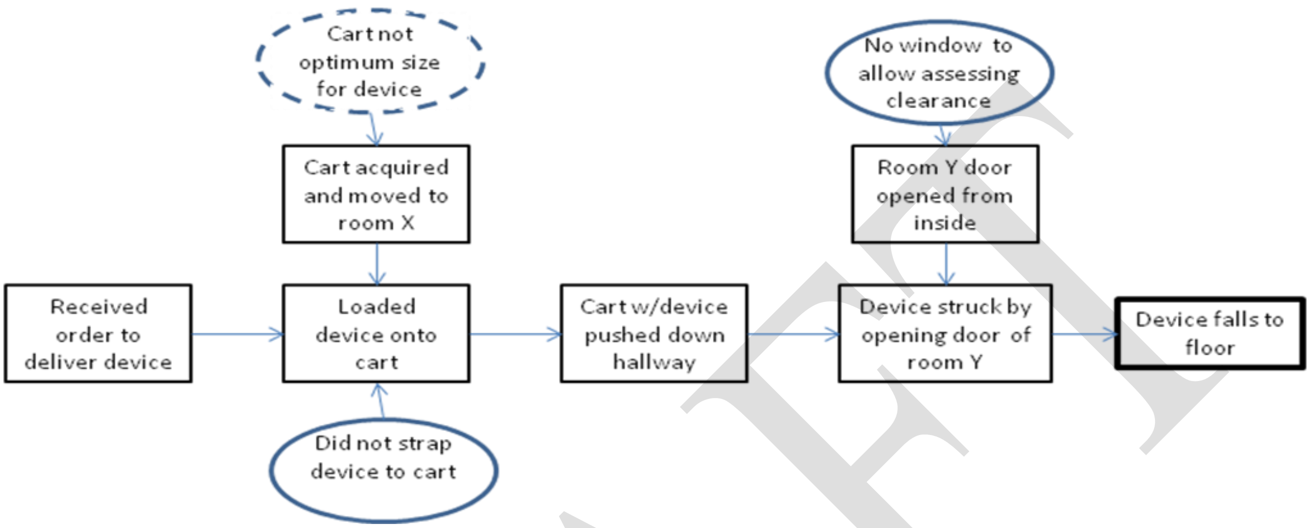
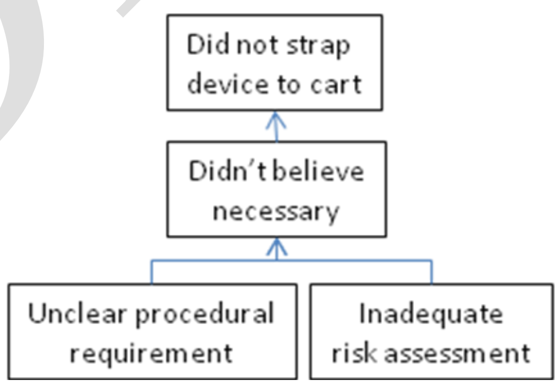


Figure 7 – Flow Chart of cart moving process

The diagram indicates that there are two direct causes: 1) The device wasn't strapped to the cart, and 2) Door Y hit the device when it opened because there was no window to allow a person inside the room to assess whether or not it was safe to open the door. There was also a contributing cause, the size of the cart. That is, had the cart been large enough it is less likely that the device would have been exposed directly to the door, and would have been more stable on the cart.

The investigators determined why each of these direct causes (and the contributing cause) occurred. This was done by performing a deeper level of investigation where the causes (did not strap device to cart, and no window in door) now become the problem. Possible causes for each were identified, and data was collected and analyzed. The logic trees in figure 8 show the problem causes. They were created by asking "why?" at each level. For additional information on logic trees see Appendix 2-3



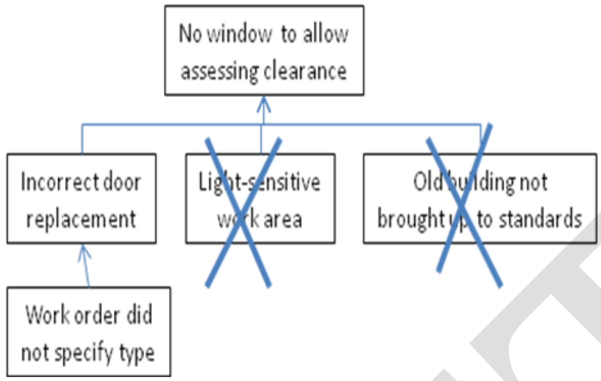


Figure 8 – Logic Trees for Problem Causes

Note that in each case investigators can decide to address the problem at this new level of cause, or to go to the next deeper level. Such decisions are made based on the frequency, impact and risks associated with the problem/cause at each level. Often this sort of problem may be evaluated using Human Performance Improvement techniques instead of or in conjunction with RCA tools.

Appendix 2 – Tools for RCA Problem Solving, Data Collection, and Analysis

The following Appendices describe tools that may be used during root cause analysis. There are many more tools than those illustrated in this procedure including specialized software such as TapRooT®. Experience and training will guide users in determining the best tools to use in any given situation and in any given step of the RCA process.

Tools illustrated in one RCA step may apply to other steps as well. These steps may be iterative. For example, as more information is obtained, it may be beneficial to refine the problem statement.

Appendix 2 – 1 RCA Step 1 Define the Problem

Step 1 utilizes a number of tools including the Pareto chart and run chart to arrive at as precise a problem statement as possible. The definition may be further refined as the RCA continues. In order to create Pareto and run charts it may be necessary to use check sheets (Appendix 2-4) or other data collection tools.

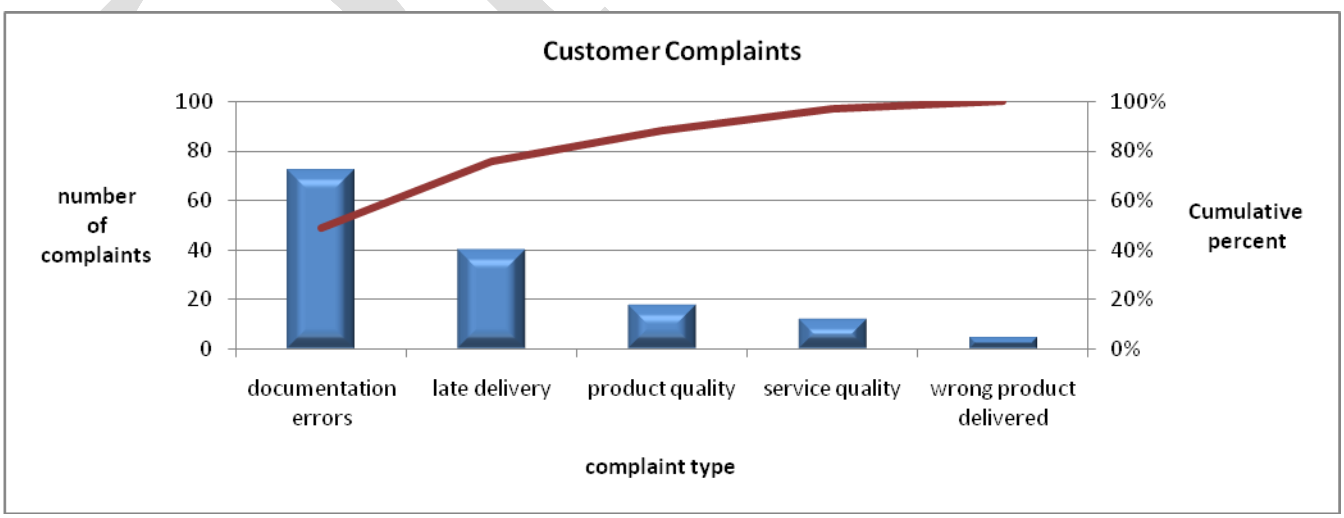
Pareto Chart

A **Pareto Chart** is a type of chart that may contain both bars and a line graph. It displays the values in descending order as bars and the cumulative totals of each category, left to right, as a line graph. The left vertical axis is the frequency of occurrence, but it can also represent cost or other units of measure. The right vertical axis is the cumulative percentage of the total number of occurrences, total cost, or total of the particular unit of measure.

The purpose of the Pareto chart is to highlight the most important of a set of factors. It often represents the most common source of defects, the highest occurring type of defect, or the most frequent reason for service interruptions, customer complaints and so on. In the example below, it is immediately evident that "documentation errors" is the major cause of customer complaints, accounting for approximately 50% of all complaints.

During root cause analysis this tool is useful for determining, categorizing, and displaying information that may help better define the problem. For instance, the chart below further defines the problem "customers are complaining" into the reasons for complaints and identifies that 50% of complaints are for documentation errors. When multiple causes are identified later in the RCA, it may also be useful in determining the most important cause or causes to resolve in order to reduce or eliminate the problem. For more information on Pareto Charts see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of Pareto Charts in problem solving.



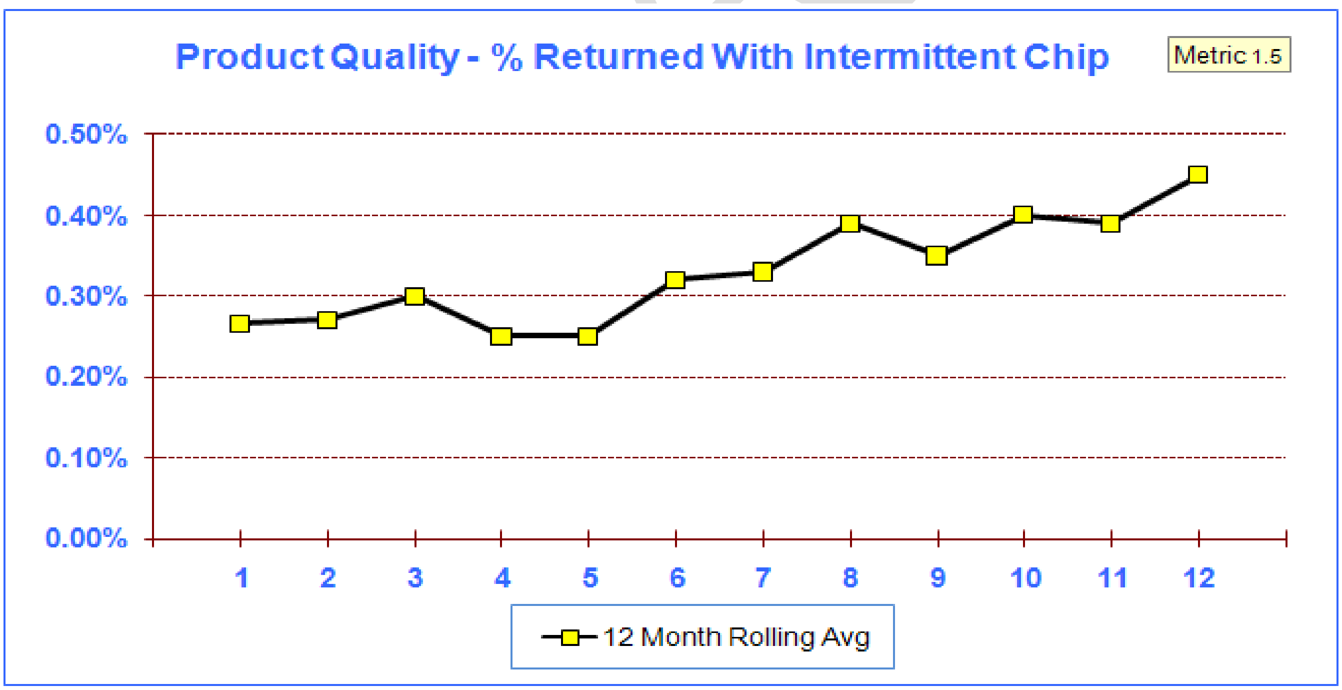
Run Chart

A **Run Chart** is a graph that displays data in a time sequence. Often, the data represent some aspect of the performance of an activity or a process. The run chart plots values representing observations on the vertical axis and the times they were observed on the horizontal axis.

The run chart is used to analyze data to detect trends, shifts or patterns over time. It allows the comparison of process performance before and after a process or activity has changed. In the example below a team is investigating system performance problems. They analyze data for the percent of returns with a malfunction over a period of twelve months. When defining the problem this chart helps refine a problem statement like "error rates were high this year" to "chip performance error rates have increased from 0.25% in month 5 to 4.5% in month 12". The cause of the marked increase in chip errors could be a contributing cause of system performance problems like the one under investigation.

During root cause analysis this tool is useful for displaying and analyzing process behavior over time. It is particularly useful in detecting changes in process behavior. For more information on Run Charts see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of a Run Chart in problem solving



Like the Pareto chart, the run chart is often useful during the data analysis step.

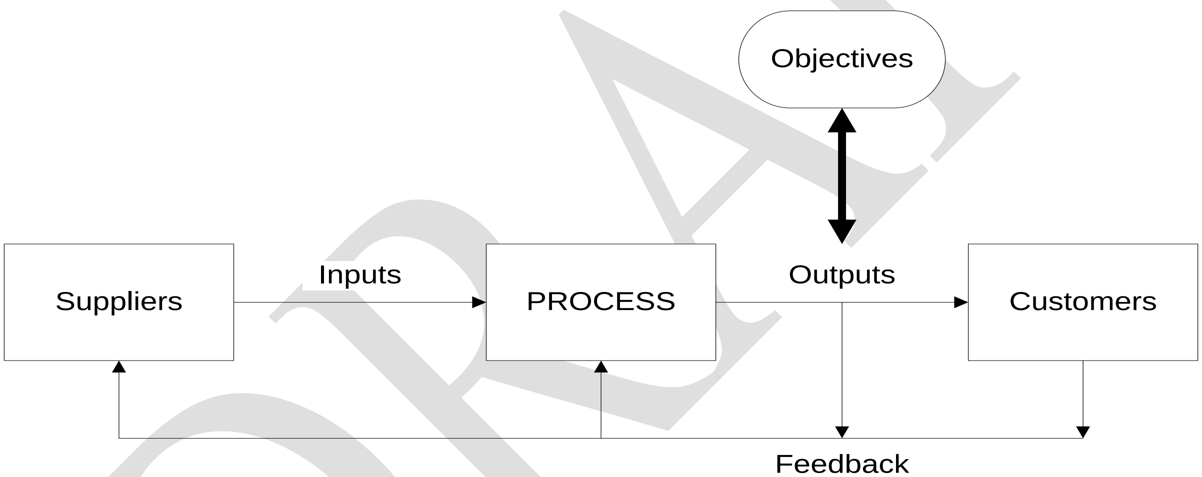
Appendix 2-2 – RCA Step 2 Understand the Process

Step 2 utilizes flow charting tools to understand and visualize the process that caused the problem. The completed flow charts will show process boundaries, sequence of operations, and timelines.

SIPOC

Supplier, Input, Process, Output, Customer (**SIPOC**) describes the high level structure for a flow chart. Suppliers deliver inputs which are then processed to produce outputs. The outputs are delivered to customers. The outputs need to meet the objectives in order to satisfy customers. These objectives may include product features, quality levels, on-time delivery, etc. Finally, feedback from customers, the outputs, and the process are used to improve suppliers, the process and ultimately outputs in order to improve customer satisfaction.

During RCA evaluations this chart may be helpful in identifying high level process boundaries which is useful when defining the scope of the RCA. For more information on SIPOC see Root Cause Analysis the Core of Problem Solving and Corrective Action by Duke Okes.



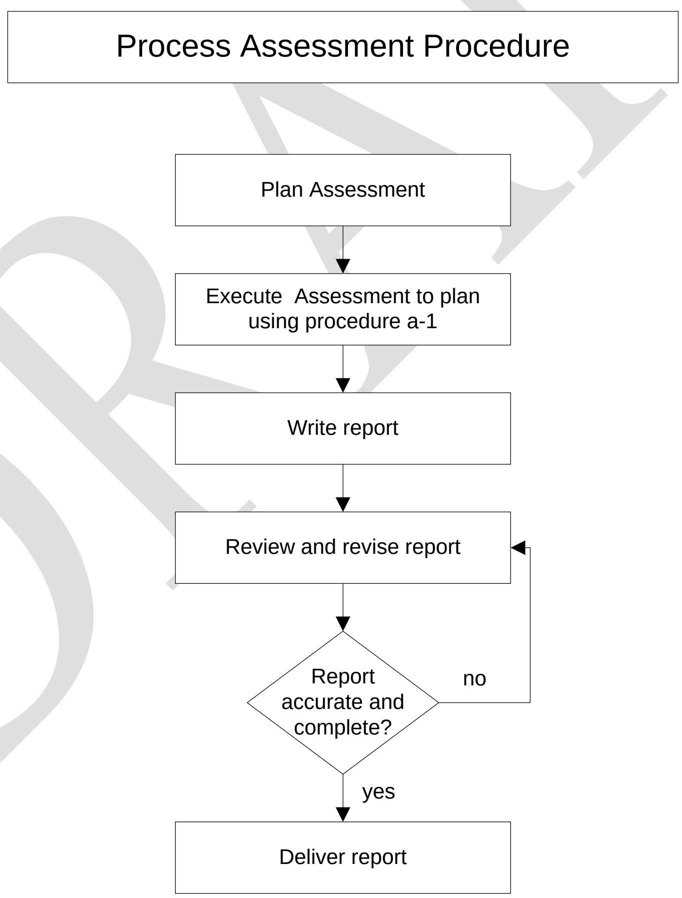
Process Flowchart

A **flowchart** is a type of diagram that represents an algorithm or process. A flowchart shows the steps of the process as boxes and the order of the steps by using arrows to connect the boxes. Flowcharts are used to analyze, design, document, or manage a process or program. More sophisticated flowcharts may employ other specialized shapes, symbols and graphics to represent the steps and events in a process.

In the example below the order in which each task of the assessment process is completed is clearly identified. In addition, there is a feedback loop for reviewing and revising the assessment report and the process output is the report.

During root cause analysis this tool is useful for defining the process in order to identify possible areas where problems or defects may be encountered. For more information on Flowcharts see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, examples 1 and 2 for a demonstration of the use of a Flow Chart in problem solving.



Appendix 2-3 – RCA Step 3 Identify Possible Causes

Step 3 utilizes the flow chart developed in RCA step 2 (Appendix 2-2) along with other tools described in this Appendix to determine which is the most likely cause or source of the problem.

5 Whys

The **5 Whys** is a question asking methodology used to determine the cause/effect relationships underlying a particular problem. The purpose of applying the 5 whys is to determine the root cause of a problem. The process begins with a problem statement. The question why is then asked to determine why the problem exists. When the answer to the first question has been determined, the question why is asked again relative to the answer. The question why is asked and answered a total of 5 times (more or less if necessary) in order to determine the root cause of the problem. In the example below, using the problem statement "the product does not meet customer needs", successive whys are asked until the root cause of the problem is determined:

- Why does the product not meet customer needs?
  - Because of one or more issues with delivery, features, or defects
- Why did we miss the delivery deadline?
  - Because requirements changes caused development delays
- Why?
  - Because engineering changed the drawing
- Why?
  - Because the customer requested new features

During root cause analysis this tool is useful for determining, categorizing, and displaying effects and potential causes. For more information on the 5 "Whys" see Root Cause Analysis the Core of Problem Solving and Corrective Action by Duke Okes.

The logic tree (see below) provides a graphical representation of the application of the 5 Whys. The tree grows as more branches are added to it as a result of asking the 5 "whys"

See Appendix 1, example 1 for a demonstration of the use of the 5 "whys?" in problem solving

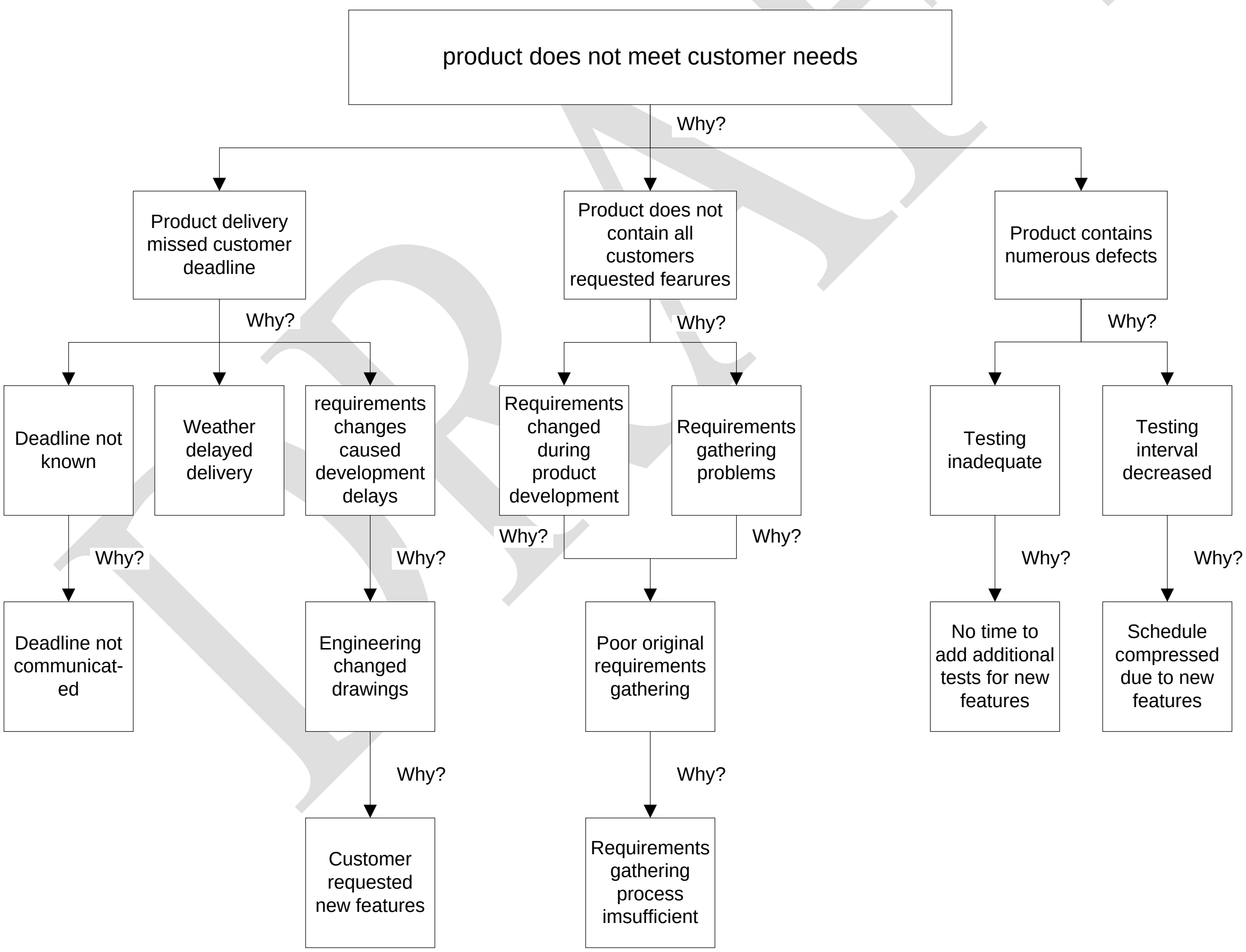
Logic Tree

A **Logic Tree** is a diagram that shows the causes of events and the relationship among events. It is used to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation.

The Logic Tree can be constructed with the help of the 5 Whys Tool (see above). After defining the initial problem or event, use the 5 Whys tool to find the causes of each succeeding branch of the tree, until arriving at the root causes. In the example below "why?" is asked of the problem statement and again for each answer until the root causes are reached for each major branch.

During root cause analysis this tool is useful for determining, categorizing, and displaying root causes. For more information on Logic Trees see Root Cause Analysis the Core of Problem Solving and Corrective Action by Duke Okes.

See Appendix 1, examples 1 and 2 for a demonstration of the use of a Logic tree in problem solving



Logic Trees may also be constructed using AND or OR operators which are not illustrated here. AND is used to indicate when multiple lower level causes can only result in the problem when each of them is in a specified state at the same time. OR is used to indicate when any one or more lower level causes can result in the problem independently.

Brainstorming

Brainstorming is a method for generating a large number of ideas about the potential causes or sources of the problem quickly. Typically, the problem description is recorded on a flip chart so the entire group can see it. Using the flip chart, one person acts as the recorder and writes down ideas about the possible causes or sources of the problem as participants offer them. Participants are encouraged to generate as many possible causes or sources as possible with no evaluation or judgment made. Once the team has stopped generating potential causes or sources, they are clarified and duplicates eliminated. This leaves the team with a large list of possible causes or sources of the problem. These may be reduced through the use of quality tools such as Nominal Group Technique or Multi-voting, found in Appendix 2-6.

During root cause analysis this tool is useful for generating a list of potential problems to be resolved or for generating a list of potential causes for an identified problem. For more information on Brainstorming see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of Brainstorming in problem solving.

Cause and Effect Diagram

A **Cause and Effect Diagram** is a diagram that shows the causes of an event. The cause and effect diagram (also called **fishbone diagram** or **Ishikawa diagram**) is used to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Note: this definition of cause and effect diagram is different than that used by the DOE in *Root Cause Analysis Guidance Document, DOE-NE-STD-1004-92.*

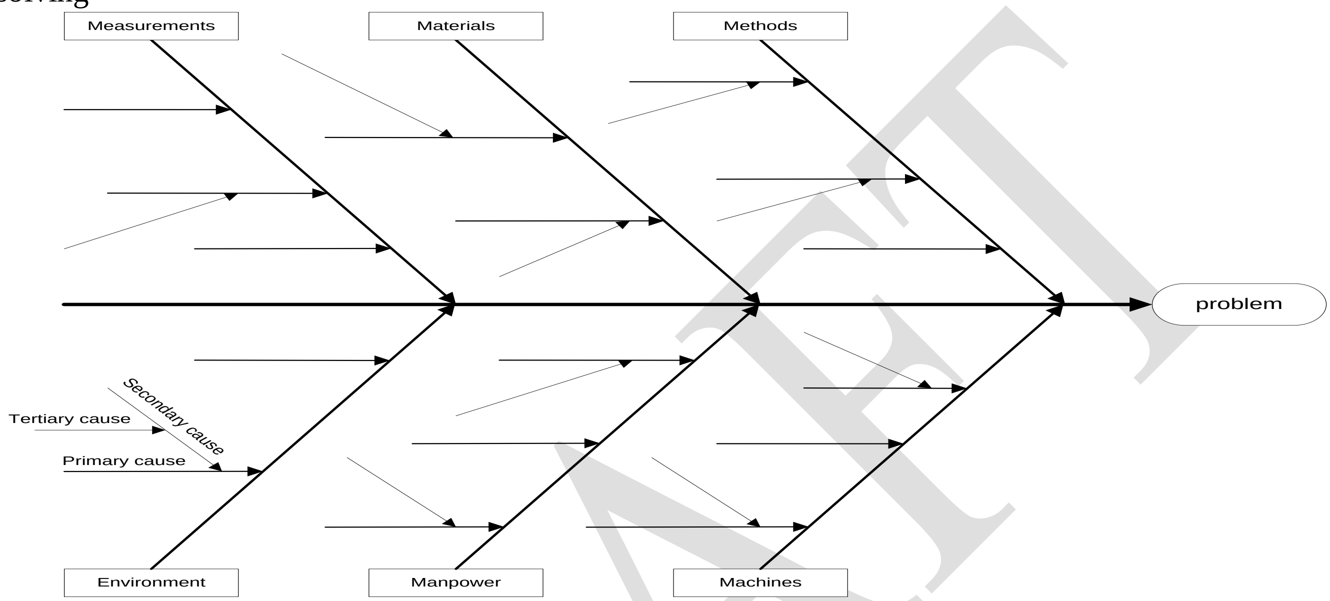
The effect or problem is stated on the right side of the chart and the major influences or causes are listed on the left. Causes are grouped into major categories to identify the sources of variation. The categories typically include:

- Manpower: people involved with the process
- Methods: How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations, and laws.
- Machines: Any equipment, computers, tools, etc. required to accomplish the job
- Materials: Raw materials, parts, pens, papers, etc. used to produce the final product
- Measurements: Data generated from the process that are used to evaluate its quality
- Environment: the conditions such as location, time, temperature and culture in which the process operates.

In the example below, it can be seen that the major causes of the problem are broken down further into primary, secondary, and tertiary causes which fill in the “bones” of the fish

During root cause analysis this tool is useful for determining, categorizing, and displaying root causes. For more information on Cause and Effect Diagrams see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of a Cause and Effect Diagram in problem solving



Barrier Analysis

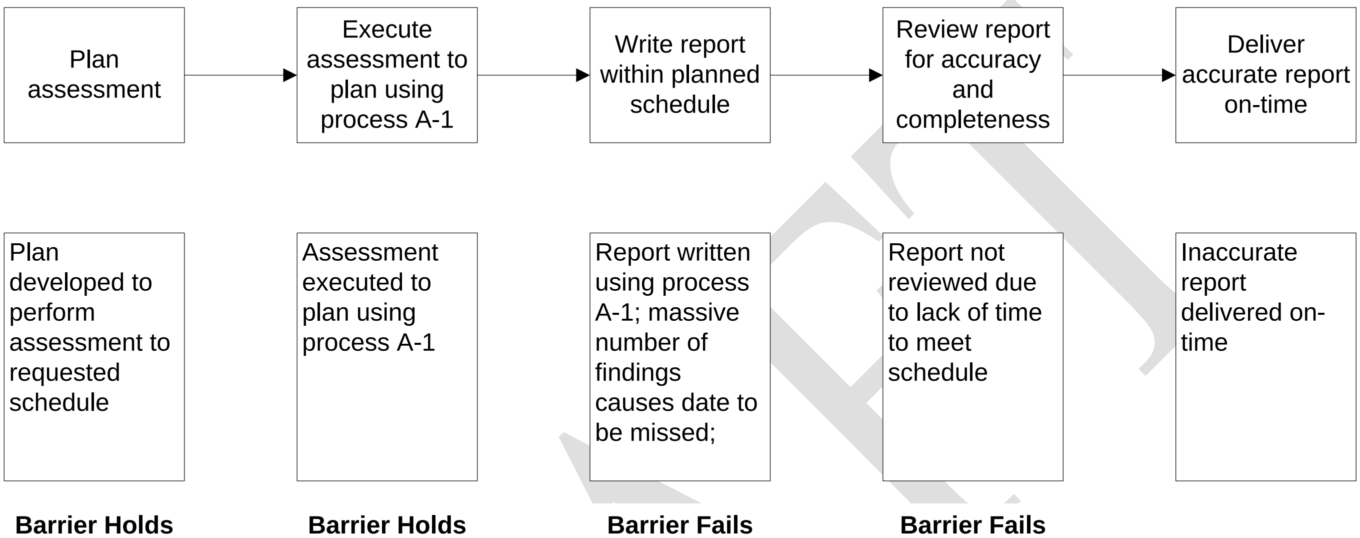
Barrier analysis is a process used to identify failures in processes and systems. It begins by identifying the process failure. Next, the barriers already in place to protect against this failure occurring are identified. Then it is determined which of the barriers were effective and which failed, causing the problem. Next, it is determined what additional barriers need to be developed to ensure the failure does not happen again. Finally, a plan is developed to implement the new barriers and to strengthen existing barriers.

In the example below, the process failure is the delivery of an inaccurate report. Two Barriers held – planning the assessment and executing the assessment using the process, and two barriers failed – writing the report to schedule and reviewing the report. The failed barriers caused the overall process failure.

During root cause analysis this tool is useful for determining, categorizing, and displaying root causes, especially failure of process steps intended to prevent the problem from occurring or intended to detect an occurrence of the problem. For more information on Barrier Analysis see Root Cause Analysis the Core of Problem Solving and Corrective Action by Duke Okes.

See Appendix 1, example 1 for a demonstration of the use of Barrier Analysis in problem solving

Process Assessment Procedure – Barrier Analysis



Appendix 2-4 RCA Step 4 Collect Data

Step 4 utilizes data collection tools such as the check sheet to collect data to either confirm or refute the possible causes of the problem identified in step 3. More specialized data collection instruments may be used for some situations. For example when collecting data for a statistically designed experiment or a simple component swap out experiment, the collection form may be organized by experimental run number and may display the levels of factors being varied during each experimental run.

Check Sheet

A **Check Sheet** is a structured form that is used for collecting data in real time at the location where the data is generated. The check sheet is typically a blank form that is designed for the quick, easy, and efficient recording of the desired information, which can be either quantitative or qualitative.

A defining characteristic of a check sheet is that data is recorded by making tally marks ("checks") on it. A typical check sheet is divided into regions, and marks made in different regions have different significance. Data is read by observing the location and number of marks on the sheet. The check sheet is most useful when collecting data on the frequency or patterns of events, problems, defects, defect location, defect causes, etc.

In the example below reasons for product returns are recorded on the check sheet. For each reason, the number of returns is recorded per day. This allows the total returns for each day of the week and the total returns for each reason for the week to be easily calculated.

During root cause analysis this tool is useful for collecting and recording data. For more information on check sheets see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

Reason for return	Week 1					
	Monday	Tuesday	Wednesday	Thursday	Friday	Total
scratch	III	𝍸 II	II	II	𝍸 III	22
snag	I	𝍸	III	II	III	14
Missing piece	II	𝍸	III	𝍸 𝍸 II	II	24
Wrong size	𝍸 III	III	𝍸 II	III	𝍸 𝍸 II	33
Wrong color	III	IIII	III	𝍸 𝍸 II	IIII	26
Total	17	24	18	31	29	119

Other quantitative tools include records of data collected during a multi-vari study or a statistically based sampling activity. Some qualitative data collection tools include interviews, observations, review of records and logs, and pictograms concentration diagrams) to illustrate spatial orientation (location) of symptoms of the problem. Sometimes specialized laboratory tests may provide useful types of data.

Appendix 2-5 RCA Step 5 Analyze the Data

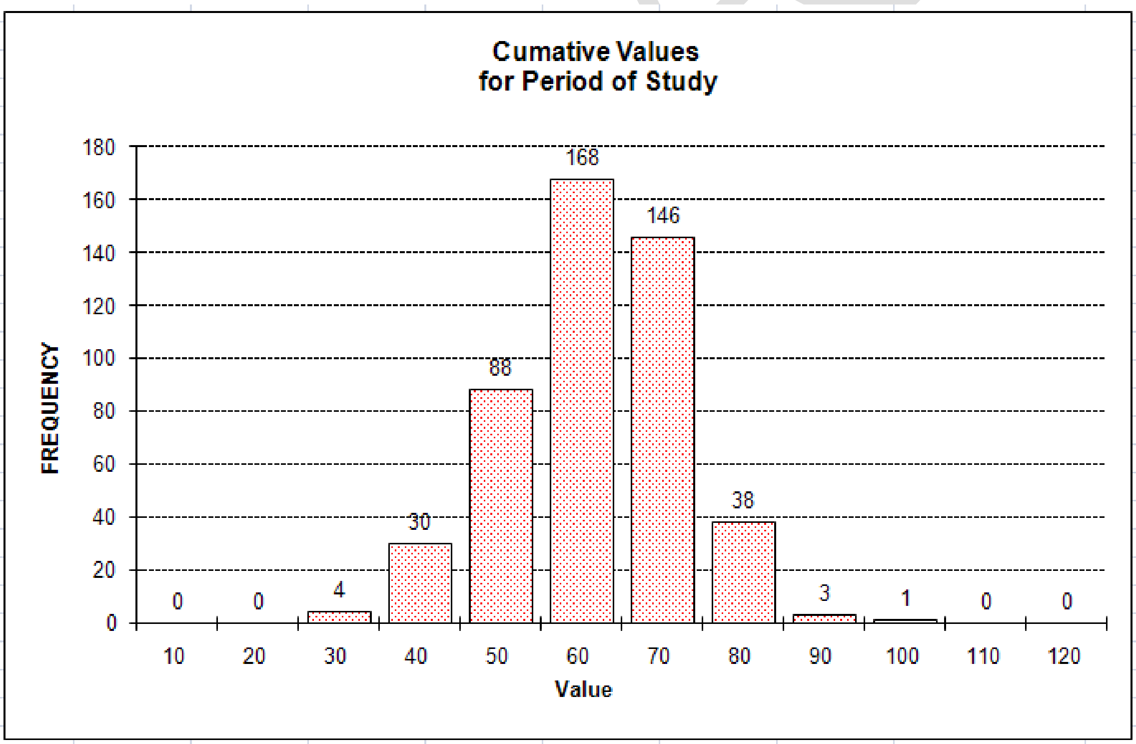
Step 5 utilizes data analysis tools to determine which of the identified causes is the true root cause of the problem. The tools to use on a specific problem are dependent on the types of data available and the frequency of the problem.

Histogram

A **Histogram** is a graphical display of a frequency distribution. It shows how often different values in a set of data occur within predetermined bins . It can be used to summarize data from a process that has been collected over time. It is important to understand the frequency distribution of any data set prior to performing any formal statistical analysis. To construct a histogram individual observations are counted in bins located on the x-axis and the frequency in each bin is plotted on the y-axis. There are a number of rules of thumb and formulas available to determine the optimum number of bins for a given data set.

In the example below the center of each bin is displayed as 30, 40, 50 and so on. The value 30 represents observations in the range (bin) 26 to 35, the value 40 represents observations between 36 and 45 and so on. The y-axis indicates a frequency of 4 observations in the first bin, 30 observations in the second bin, 88 observations in the third bin and so on.

During root cause analysis this tool is useful for displaying and analyzing the frequency distribution of data. For more information on Histograms see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

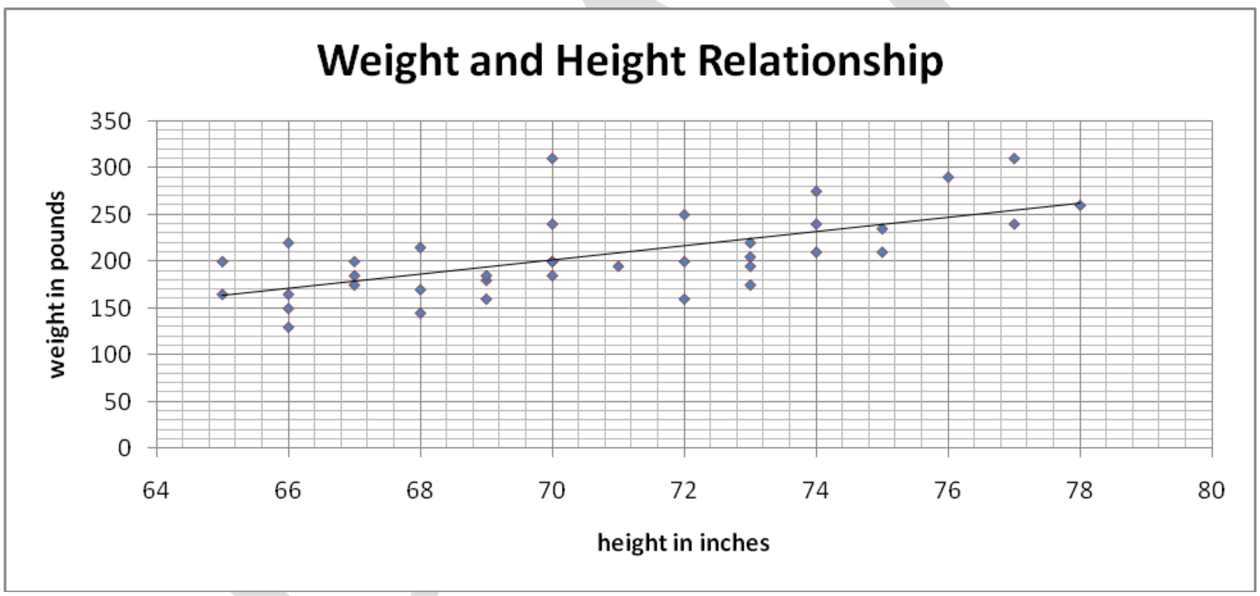


Scatter Diagram

A **Scatter Diagram** is a type of diagram that displays pairs of numerical data, with one variable on each axis, to look for a relationship between them. The data is displayed as a collection of points with each point having the value of one variable determining its position on the horizontal axis and the value of the other variable determining its position on the vertical axis. The points suggest various kinds of correlations between the variables such as positive (rising), negative (falling), or null (uncorrelated). A line of best fit (sometimes called a trend line) can be drawn to study the correlation between the variables.

In the example below weight and height of individuals are the 2 variables plotted on the graph. A trend line has been drawn which shows a positive (rising) correlation between weight and height – that is, as weight increases, height tends to increase as well.

During root cause analysis this tool is useful for displaying and analyzing the relationship or correlation between 2 variables. For more information on Scatter Diagrams see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

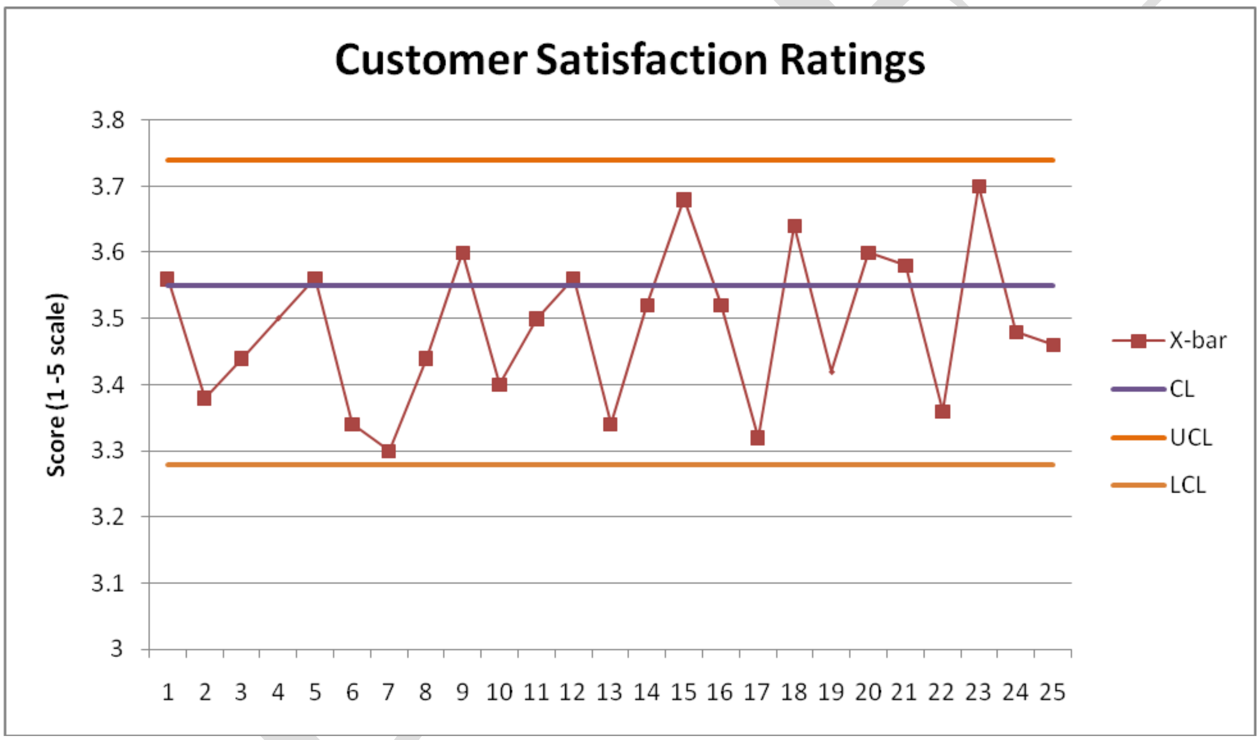


Control Chart

A **Control Chart** is a graph used to study how a process changes over time. A control chart is really a run chart that contains statistically determined upper and lower control limits drawn on either side of the process average center line. The control limits indicate the threshold at which the process is considered to be in or out of control. Control charts are often interpreted using additional rules such as the number of consecutive values above or below some value or an upward or downward trend inside the control chart lines.

Variations of the process points within the control limits are due to variation built into the process, also called common causes. Variation of the process points outside the control limits (and other rules violations) are due to causes outside the process, also called special causes. The purpose of control charts is to monitor, control, and improve process performance over time by detecting variation and its causes. In the example below the process is considered to be in control, because all points lie between the upper and lower control limits. Variation in individual points is due to variation built into the process, also known as common cause.

During root cause analysis this tool is useful for displaying and analyzing process behavior over time. By investigating conditions leading to out of control situations it is possible to uncover clues as to the underlying causes. For more information on Control Charts see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html



Statistical Techniques

Statistical techniques are formal statistical models, methods and procedures used to analyze results of experiments or to monitor process outcomes as time series. Most of these techniques are beyond the scope of this document. A few types of statistical techniques are process capability analysis, Hypothesis Tests, Design of Experiments, and Regression Analysis. For more information on Statistical Techniques visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

Appendix 2-6 Identify Possible Solutions & Select Solutions to be Implemented

Evaluation and Decision Making Tools
The activities in this appendix take place after the root cause (or causes) has been identified. As such, they are not part of the RCA process steps per se. However, they do help with the next logical activity and are therefore described here. The tools described for this activity are used to identify solutions and then select which solutions to implement. Creativity tools such as brainstorming (Appendix 2-3) may be used to identify possible solutions, while the decision tools described below are used to choose the most effective solution to implement.

Nominal Group

Nominal Group Technique is a structured process for determining the most (and least) important or likely causes. This process helps a team achieve consensus on the relative importance of causes. It integrates individual importance rankings into team priorities.

The Nominal Group Technique Process begins after a team has brainstormed a list of possible causes. Team members then rank each of the "n" possible causes from 1 to "n" with 1 being the highest priority and "n" being the lowest. The team leader sums the scores for each cause. The cause or causes with the lowest total are selected as the prime root causes.

In the example below operator error (7) and poor raw material (9) are the most important causes as determined by voting of the team members.

During root cause analysis this tool is useful for evaluating multiple root causes to determine the most important ones to resolve to reduce or eliminate the problem. For more information on Nominal Group Techniques see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of Nominal Group Technique in problem solving.

potential cause	Jean	John	Barb	Mary	Steve	Total
poor raw material	2	1	3	1	2	9
bad machine set-up	3	4	2	3	3	15
operator error	1	2	1	2	1	7
improper packing	4	3	4	4	4	19

1 = most important
4 = least important

Multi-Voting

Multi-Voting is a structured process for determining the most important root causes. This process helps a team achieve consensus on the importance of causes. It integrates individual importance rankings into team priorities.

The multi-voting process begins after a team has brainstormed a list of possible root causes. Each team member is given "x" votes, where x = (total number of causes identified)/2 +1. The team members can spread their votes over the root causes in any manner. The team leader adds up the scores for each cause and the high vote getters are then focused on as the prime root cause. Multiple rounds of voting can be used to get the prime root causes down to a target number.

In the example below poor raw material (7) and operator error (6) and are the most important causes as determined by voting of the team members. During root cause analysis this tool is useful for evaluating multiple root causes to determine the most important ones to resolve in order to reduce or eliminate the problem. For more information on Multi-voting see The Memory Jogger II by Michael Brassard and Diane Ritter or visit the ASQ web site at: http://www.asq.org/learn-about-quality/quality-tools.html

See Appendix 1, example 1 for a demonstration of the use of Multi-Voting in problem solving.

root cause	Jean	John	Barb	Mary	Steve	Total
poor raw material	3	1	1	1	1	7
bad machine set-up					1	1
operator error		1	2	2	1	6
improper packing		1				1

votes/person = 4/2 +1 = 3

Table of Revisions

Author	Description	Revision	Date
Jed Heyes	Initial template draft	000 A	12/02/09
Duke Okes	First draft	000 A1	12/28/09
Jed Heyes, Jeff Cotton	Edits and comments to first draft	000 A2	01/06/10
Duke Okes	First revision	000 A3	01/07/10
Jeff Cotton	Edits and comments to first revision	000 A4	01/13/10
Duke Okes	Second revision	000 A5	01/18/10
Duke Okes, Jed Heyes	Addressed all comments in section 4	000 A6	01/24/10
John Martzel, Jed Heyes	Accepted final draft from Duke Okes 02/16/2010. Added Appendices 1 – 6; and information on HPI	000 B	2/24/10
John Martzel, Jed Heyes	Improved appendices 2 – 6 to become Appendix 2	000 B2	3/10/10
Jed Heyes	Added further clarifications to the appendices and more clearly identified the RCA steps to correspond with the appendices and the reference textbook for RCA.	001	3/13/10